Paper:

Efficient Optimization Using Experimental Queries: A Peak-Search Algorithm for Efficient Load-Pull Measurements

Charles Baylis*[1], Lawrence Dunleavy*[2], Steven Lardizabal*[3], Robert J. Marks II*[1], and Alberto Rodriguez*[4]

*[1]Department of Electrical and Computer Engineering, Baylor University, Waco, TX, USA
E-mail: {Charles_Baylis, Robert_Marks}@baylor.edu
*[2]Department of Electrical Engineering, University of South Florida, Tampa, FL, USA
E-mail: dunleavy@eng.usf.edu
*[3]Raytheon RF Components, Andover, MA, USA
E-mail: Steven_M_Lardizabal@raytheon.com
*[4]ITT Corporation, Palm Harbor, FL, USA
E-mail: alrodrig@mail.usf.edu

[Received September 20, 2009; accepted September 6, 2010]

In the process of hardware optimization, physical queries requiring laboratory experiments are often necessary. This is similar to optimization using software where queries are made to a computer model. In both the laboratory optimization and optimization using computer models, queries come at a cost: laboratory time or computer time. Finding efficient searches using a small number of queries on average is therefore motivated. In this paper, techniques used in computer search are shown to be transparently applicable to certain instances of hardware optimization. The hardware example presented is a load-pull peak-search algorithm for power amplifier load-impedance optimization. The successful search shown in this paper allows high-resolution measurement of the maximum power with a significant reduction in the number of measured reflection-coefficient states. The use of computationally intelligent procedures for reducing time costs in design optimization using hardware has significant potential applications in a number of iterative experimental procedures performed in the laboratory.

Keywords: load pull, steepest ascent, power, microwave, transistor

1. Introduction

In computer optimization using procedures such as genetic algorithms or hill climbing, the most computationally demanding operation is typically querying of a computer model. Thus, the query count is a metric for assessing the relative efficiency of one search algorithm over another. Search algorithms are also used in experimental optimization of hardware. Here, however, queries are made using physical laboratory measurements. The cost of a query here is laboratory time. For hardware requiring optimization of every unit, minimization of the number

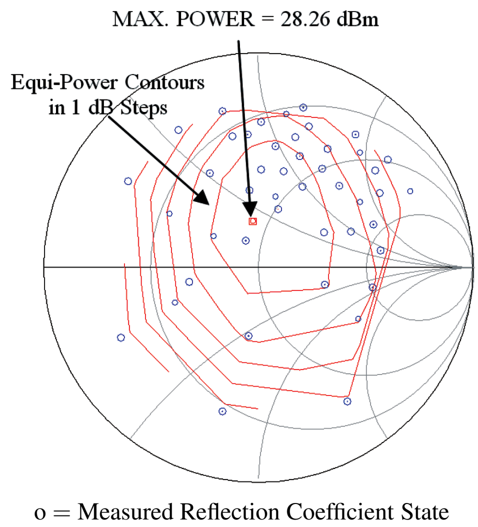


Fig. 1. Measured 3.5 GHz load-pull results for P_{in} = 14.5 dBm at $V_{GS} = -0.7$ V, $V_{DS} = 10$ V.

of queries per optimization has a multiplicative effect on the unit cost. An example is optimization of impedance loading conditions for maximum output power in amplifier design. Load-pull measurements are often used to find optimal impedance loading conditions for power amplifier design. In traditional microwave load-pull measurements, a number of reflection-coefficient states are pre-selected and measured. Contours of equal power are then fitted to the results, as shown in **Fig. 1**. In the measurement displayed, 43 different reflection-coefficient states are chosen. Approximately 4 sec are required for each measurement, requiring a total of nearly 3 min to complete the measurement. This often is not fast enough for cases in which devices must be load-pulled multiple times in order to find the maximum Power-Added Efficiency (PAE) and gain at optimum loading conditions over variations in bias, process, and often input power. This creates a demand for a better search. The purpose of this paper is to demonstrate the application of steepest ascent to a load-pull search designed to minimize the number of queries required for reflection-coefficient optimization.

Using software emulation of device physics of a GaAs *Pseudomorphic High Electron Mobility Transistor* (PHEMT) [1, 2], the authors have previously shown that a steepest ascent procedure significantly reduces the number of queries required for optimization. In addition to reducing characterization time in the laboratory, these methods can be used in on-chip load-pull to determine the optimum loading condition for a new frequency range [3].

In searching for the best search to use in this problem, several methods have been presented in the literature. Perlow has described an algorithm that uses multiple measurements to determine the location of a contour and then, from this, ascend [4]. De Hek et al. have described a method that begins with measured points at a significant radius on the Smith Chart and calculates the location and value of the maximum power from a function fit to the data points. The search is repeatedly reiterated at smaller radii until the solution converges with respect to power and Smith Chart location for decreasing radius of the measurements [5]. A genetic algorithm was employed by Qiao et al. for on-chip optimization of a reconfigurable power amplifier [3], but such algorithms are prone to require a significantly larger number of queries than the steepest ascent method, consistent with the conclusions of Copalu [6] that the steepest ascent method is often advantageous because it can work under arbitrary criterion functions.

2. The Steepest-Ascent Algorithm for Load-Pull

The problem at hand is the optimization of the change in output power (relative to the starting point) over changes in the real and imaginary parts of the load reflection-coefficient: $\Delta P(\Delta\Gamma_r,\ \Delta\Gamma_i)$. The desire is to choose, with as few queries as possible, the combination of real and imaginary part of the load reflection-coefficient $(\Delta\Gamma_r,\ \Delta\Gamma_i)$ that maximizes the output power delivered from the transistor to the load. For this optimization, the criterion is output power, and the parameters to be adjusted to optimize the criterion are the real and imaginary parts of the load reflection-coefficient $\Delta\Gamma_r$ and $\Delta\Gamma_i$, respectively. The variables $\Delta\Gamma_r$ and $\Delta\Gamma_i$ can thus be plotted on a *Smith Chart* as used, for example, in **Fig. 1**. Varying the complex load reflection-coefficient throughout the Smith Chart and measuring at different reflection-coefficients in order to optimize output power is known as "load-pull." The search described in this section is designed to minimize the number of queries necessary to find the optimum-power combination of $\Delta\Gamma_r$ and $\Delta\Gamma_i$.

The search is divided into initial and final stages [7]. Two neighboring points are measured in each direction about the starting point at a distance D_n, changing only one of the coordinates for each point, as shown in **Fig. 2**. From these three measurements, an equation for a plane

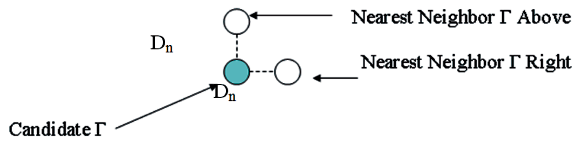


Fig. 2. Measurements to extract tangent plane equation and direction of steepest ascent.

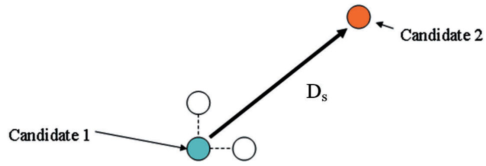


Fig. 3. Measurement of power at a new candidate point.

tangent to the response at the starting point can be constructed:

$$\Delta P(\Delta\Gamma_r, \Delta\Gamma_i) = m_1\Delta\Gamma_r + m_2\Delta\Gamma_i. \quad (1)$$

From measurements of power at the candidate and the two nearest neighbors (as shown in **Fig. 2**), two values of ΔP are obtained by subtracting the power at the candidate point from the power at both of the nearest neighbors. Substituting these values of ΔP and the associated values of $\Delta\Gamma_r$ and $\Delta\Gamma_i$ in Eq. (1) can be used to solve for m_1 and m_2. By setting $\Delta P = 0$, the equation for the line tangent to a contour of equal power is found to be

$$\Delta\Gamma_i = -\frac{m_1}{m_2}\Delta\Gamma_r. \quad (2a)$$

The equation for the line in the direction of the maximum rate of increase is perpendicular to the line of Eq. (2a) and is thus

$$\Delta\Gamma_i = \frac{m_2}{m_1}\Delta\Gamma_r. \quad (2)$$

D_s, the search distance, is the predetermined distance from the present candidate point to the subsequent candidate point. The next candidate point is found by proceeding a distance D_s to the next candidate point along the line of steepest ascent. It lies on the intersection of the circle

$$\sqrt{(\Delta\Gamma_r)^2 + (\Delta\Gamma_i)^2} = D_s \quad (3)$$

with the steepest-ascent line in Eq. (2). There are be two solutions for the intersection point, as the line of steepest ascent also serves as the line of steepest descent if followed in the opposite direction. The intersection point solution having a value of $\Delta P > 0$ from Eq. (1) is selected the second candidate point, as shown in **Fig. 3**. This point is then measured, and if a power increase is obtained, then the process is repeated for Candidate 2. If not, the search distance D_s is decreased to one-third of its initial value and another candidate is measured. The search proceeds to its conclusion when D_s falls below a predefined threshold.

At the end of the search (when $D_s < D_n$), five points are chosen around the final candidate point to extract

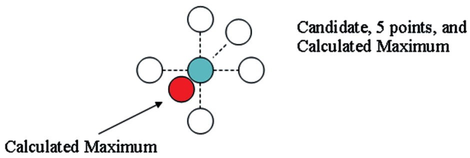


Fig. 4. Implementation of the final search stage.

a second-order polynomial approximation in the two reflection-coefficient variables:

$$\Delta P = m_1 \Delta\Gamma_r + m_2 \Delta\Gamma_i + \frac{1}{2}[m_{11}(\Delta\Gamma_r)^2 + 2m_{12}(\Delta\Gamma_r)(\Delta\Gamma_i) + m_{22}(\Delta\Gamma_i)^2] \quad . \; . \; . \; . \; (4)$$

Eq. (4) is a traditional second-order polynomial approximation in the two variables $\Delta\Gamma_r$ and $\Delta\Gamma_i$. A second-order equation is necessary to allow a maximum of the function to exist. This is important because the equation will be used to calculate both the power that can be delivered by the device and the combination of $\Delta\Gamma_r$ and $\Delta\Gamma_i$ that provide this maximum power. The candidate points used here are the points taken four directions from the center point (the points to the right and left of the center point will have already been measured at this point in the search), along with a fifth point that can be selected by the algorithm. The maximum of this function can be calculated by setting the gradient of Eq. (4) equal to zero and solving for $\Delta\Gamma_r$ and $\Delta\Gamma_i$, and then finding the associated value of ΔP from Eq. (4). **Fig. 4** shows an intuitive description of the final search stage.

Because Perlow's algorithm [4], while being a steepest-ascent type, spends many measurements finding the equi-power contour rather than searching for the steepest ascent direction, the method presently proposed based on [7] generally uses fewer measurements than the Perlow method. Because the method of de Hek [5] utilizes a "zoom-in" approach from the edge of the Smith Chart toward the center, it allows many measurements during its initial stages in regions of the Smith Chart far away from the optimum point, some of which could provide damage to the device due to the large power mismatch. Berghoff et al. [8] have proposed a method in which the phase and attenuation of the load tuner are iteratively optimized one at a time; however, optimizing one variable at a time may not result in finding the maximum[1] [7].

3. Algorithm Simulation Results

The initial testing of the accuracy and efficiency of this algorithm were performed by using MATLAB to control load-pull simulations in Agilent Technologies' Advanced Design System (ADS) software [9]. Simulation results are briefly reviewed here [1]. **Fig. 5(a)** shows traditional load-pull simulation contours of equal output power for a GaAs Pseudomorphic High Electron Mobility Transistor (PHEMT) model. **Fig. 5(b)** shows a plot of the candidate points and the search algorithm paths traversed from five different starting points. It can be seen that, for each of these starting points, the algorithm converges to essentially the same reflection-coefficient value for the maximum power; in addition, this point is identical to the maximum-power reflection-coefficient seen in **Fig. 5(a)**. The MATLAB/ADS co-simulation found the maximum power for the HEMT model to be 22.72 dBm with simulation of only 17 reflection-coefficient states, while a simulation using a traditional ADS load-pull simulation with 400 different values of Γ_L found the maximum power to be 22.76 dBm. **Table 1** shows the starting reflection-coefficient, the final reflection-coefficient, the maximum-power reflection-coefficient, the maximum power, and the number of simulated states for each starting point in the peak searches performed.

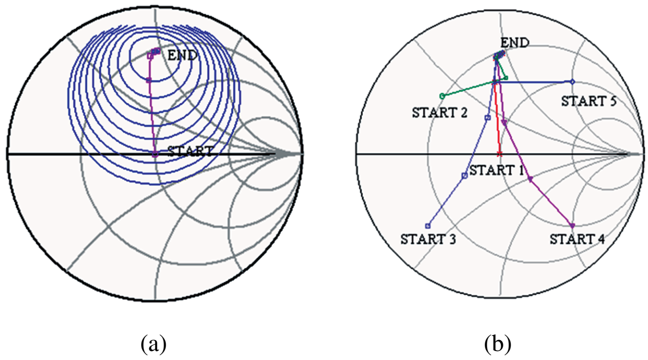


Fig. 5. (a) Load-pull search path from MATLAB/ADS algorithmic implementation with output power contours generated from traditional ADS load-pull simulation, and (b) search algorithm progress for five different starting points.

Table 1. MATLAB/ADS simulation results for different searches.

Starting Γ_L	Maximum Output Power Γ_L	Maximum Output Power (dBm)	Number of Sim. Points
0 + j0	0.689 <90.05°	22.7184	17
0.5 + j0.5	0.690 <90.14°	22.7178	17
0.5 − j0.5	0.690 <90.05°	22.7154	19
−0.5 − j 0.5	0.690<90.05°	22.7154	17
−0.4 + j0.4	0.694 <89.98°	22.7143	14

Each search results in a maximum-power value and reflection-coefficient that should ideally be identical to the results from the other searches. The maximum reflection coefficient of each search corresponds to an impedance that can, in general, be represented by a series resistance R_{max} and capacitance C_{max}:

$$Z_{max} = Z_0 \frac{1+\Gamma_{max}}{1-\Gamma_{max}} = R_{max} - j\frac{1}{\omega C_{max}} \quad . \; . \; . \; (5)$$

The standard deviation in both the equivalent optimum

1. The authors are presently developing methods to protect potentially unstable devices from going into oscillation during the load-pull search.

resistance R_{max} and the equivalent optimum capacitance C_{max} are useful measures of the variation of optimum end-point locations across the different searches. These can thus be used to assess the repeatability of the optimum endpoint. The standard deviation of the power value allows a measure of the repeatability of the optimum criterion value over the different searches. For the results shown, the optimum load resistance and capacitance mean and standard deviation have been found. The mean load resistance is 17.705 Ω with a standard deviation of 0.101 Ω, while the equivalent load capacitance is −3.407 pF with a standard deviation of 0.5738 fF. Excellent agreement has been achieved for the optimal load impedance despite different starting points for the search iterations.

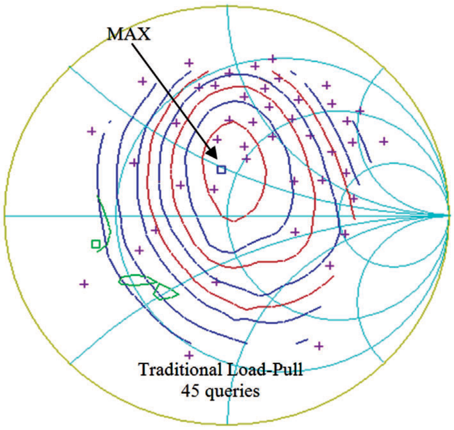
4. Algorithm Measurement Results

Measurement testing involved the development and use of a MATLAB graphical user interface to control the Maury Microwave ATS Version 400 load-pull system and software [10]. The measurement system includes a load-pull tuner that is adjusted to desired values of Γ_L to the device output, and a power meter to measure the output power for each value of Γ_L. **Fig. 6(a)** shows the traditional load-pull results, with contours of equal output power and the maximum-power reflection-coefficient identified. **Fig. 6(b)** shows the maximum point identified by the peak-search algorithm, along with four different starting points used in the testing and the number of measurement queries necessary to obtain the optimum when starting from these points. It can be seen that, even from significant distances from the optimum, the search converges with a small number of queries.

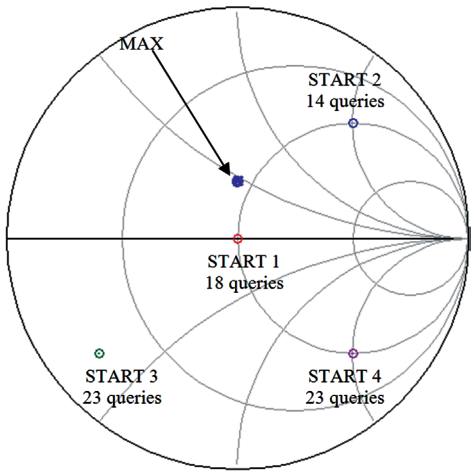
As in the simulation case, the robustness of the measurement search results for different starting points on the Smith Chart was tested. **Table 2** shows the $P_{in} =$ 14.5 dBm (1-dB compression) search results for the use of the four different starting impedances shown in **Fig. 6(b)**. The mean value of resistance (R_{max}) was found to be 44.283 Ω, with a standard deviation of 1.443 Ω. The capacitance (C_{max}) was found to have a mean value of −679.8 femto Farads (fF), with a standard deviation of 17 fF. The mean power value was found to be 28.311 dBm, with a standard deviation of 0.011 dBm. All four maximum power values are within 0.03 dBm of each other. These metrics all demonstrate excellent correspondence between results in the microwave measurement field.

5. Power-Swept Load-Pull

The value of Γ_L providing maximum output power migrates as the device moves from small-signal to large-signal operation. As the input power is increased, the values of maximum-power Γ_L at different power levels can be recorded and plotted on a Smith Chart. This provides



(a)



(b)

Fig. 6. (a) Traditionally measured load-pull results and (b) algorithm-measured load-pull results and different starting points used.

Table 2. Measurement results for different starting reflection-coefficients at $P_{in} = 14.5$ dBm.

Starting Γ_L	Maximum Output Power Γ_L	Maximum Output Power (dBm)	Number of Queries
0 + j0	0.233<86.1°	28.2962	18
0.5+j0.5	0.246<89.9°	28.3132	14
0.5−j0.5	0.261<92.0°	28.3220	23
−0.6−j0.5	0.256<90.7°	28.3134	23

measured data that can be used as another means of verifying the behavior of a nonlinear transistor model.

Based on the demonstrated correspondence obtained between algorithm-driven measurements and the traditional load-pull measurements, a series of maximum power searches was performed with the algorithm at different input power values. **Table 3** shows the search algorithm results for the different input power values. All searches were performed with a starting reflection-coefficient of $0 + j0$.

Table 3. Search algorithm measurement results for different input power values with a starting reflection coefficient of $0+j0$.

Pin (dBm)	Maximum Output Power Γ_L	Maximum Output Power (dBm)	# Queries
−7	0.488<53.0°	9.9242	24
0	0.517<49.2°	15.6327	18
5	0.534<54.5°	20.3879	21
10	0.436<64.4°	25.8117	27
12	0.300<75.4°	27.4354	18
13	0.283<85.4°	27.8654	18
14	0.197<101°	28.1543	21
14.5	0.194<88.4°	28.3264	24
15.5	0.233<83.9°	28.8281	21
16.7	0.200<84.0°	28.8479	15

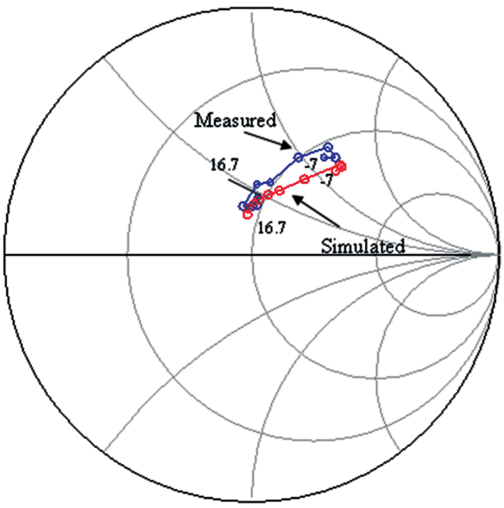


Fig. 7. Measured (upper curve) and simulated (lower curve) maximum-power reflection-coefficient for varying input power levels: −7, 0, 5, 10, 12, 13, 14, 14.5, 15.5, and 16.7 dBm.

To compare with the measured data shown in **Table 3**, simulations were performed for these input power values using an Angelov/Chalmers model [11], extracted by the authors for the PHEMT using pulsed IV, S-parameter, power sweep, and load-pull data. **Fig. 7** shows the measured and simulated migration of the maximum-power load reflection-coefficient with increasing input power. The model predicts the migration of the maximum-power reflection-coefficient with notable accuracy. This type of comparison is insightful because it shows the performance of the model at low power, high power, and medium power conditions.

To decrease the time of the power-swept load-pull measurement, a MATLAB script has been developed to run the sequence of searches more efficiently. A starting Γ_L value is specified for the first search (this would be the −7 dBm case in the above example). The maximum-

Table 4. Starting point, ending point, and number of queries for each search in the maximum-power impedance migration simulation.

P_{in}	Starting Γ	Ending Γ	Max Pout (dBm)	# Queries
−7	0<0°	0.48<44.8°	8.40	12
0	0.48<44.8°	0.51<44.0°	15.28	6
5	0.51<44.0°	0.50<45.8°	20.18	6
10	0.50<45.8°	0.37<56.6°	25.17	15
12	0.37<56.6°	0.28<68.4°	26.78	12
13	0.28<68.4°	0.25<76.2°	27.46	12
14	0.25<76.2°	0.23<84.5°	28.05	9
14.5	0.23<84.5°	0.22<88.7°	28.31	6
15.5	0.22<88.7°	0.20<96.1°	28.76	9
16.7	0.20<96.1°	0.17<102°	29.15	9

power Γ_L value from the first search is used as the starting point for the second search, and this trend is followed for all input power values to reduce the number of experimental queries. **Table 4** shows results for this "super-algorithm," and it can be seen that the maximum number of experiments performed occurs in the first search. Only a small number of points is required for most of the subsequent searches. The number of Γ_L points ("# Queries") evaluated for each input power is decreased from **Table 3**, where a separate search was performed for each Γ_L.

6. Conclusions

Search algorithms are designed to produce better and better values of fitness through repeated queries to an oracle. Since queries come at a cost, search procedures are needed that require a small number of queries to achieve success. Although most searches are performed using a computer software oracle, the same search paradigms can be applied to the cases of experimental optimization.

This work demonstrates that search algorithms used in computer search can be applied to find efficient methods that allow a reduced number of experimental calibration queries. The search chosen provided a significant improvement over a traditional load-pull measurement.

Steepest ascent has a significant history in optimization [12]. This paper has demonstrated measurement results of an application of this work that will significantly save microwave engineers time and money by decreasing measurement queries in bench-top testing of devices.

Acknowledgements

The authors would like to thank Raytheon's University Engineering Program for financial support of this work, and specifically Alan Bielunis, Mike Adlerstein, and Steve Lichwala for their assistance. Collaboration with Maury Microwave has been invaluable. Eric Kueckels, Jon King, John Sevic, and Perry Li have assisted by providing software and technical assistance.

References:

[1] C. Baylis, S. Lardizabal, and L. Dunleavy, "A Fast Sequential Load-Pull Algorithm Implemented to Find Maximum Output Power," 2006 IEEE Wireless and Microwave Technology Conf. (WAMICON 2006), Clearwater, Florida, December 2006.

[2] The MathWorks, Inc., Natick, Massachusetts 01760-2098.

[3] D. Qiao, R. Molfino, S. Lardizabal, B. Pillans, P. Asbeck, and G. Jerinic, "An Intelligently Controlled RF Power Amplifier with a Reconfigurable MEMS-Varactor Tuner," IEEE Trans. on Microwave Theory and Techniques, Vol.53, No.3, Part 2, pp. 1089-1095, March 2005.

[4] S. Perlow, "New Algorithms for the Automated Microwave Tuner Test System," RCA Review, Vol.46, pp. 341-355, September 1985.

[5] A. P. de Hek, "A Novel Fast Search Algorithm for an Active Load-Pull Measurement System," GaAs Symposium, Amsterdam, The Netherlands, 1998.

[6] P. Copalu and P. Dangprasert, "Hybrid Genetic Algorithms: Modeling and Application to the Quadratic Assignment Problem," Assumption University J. of Technology, Vol.5, No.4, April 2002.

[7] D. Wilde, "Optimum Seeking Methods," Prentice-Hall, 1964.

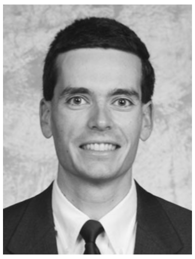
[8] G. Berghoff, E. Bergeault, B. Huyart, and L. Jallet, "Automated Characterization of HF Power Transistors by Source-Pull and Multi-Harmonic Load-Pull Measurements Based on Six-Port Techniques," IEEE Trans. on Microwave Theory and Techniques, Vol.46, No.12, pp. 2068-2073, December 1998.

[9] Agilent Technologies, Inc., Santa Clara, California 95051.

[10] Maury Microwave Corporation, 2900 Inland Empire Blvd., Ontario, California 91764.

[11] I. Angelov, H. Zirath, and N. Rorsman, "A New Empirical Nonlinear Model for HEMT and MESFET Devices," IEEE Trans. on Microwave Theory and Techniques, Vol.40, No.12, December 1992.

[12] R. Reed and R. J. Marks II, "Neural Smithing," (MIT Press), 1999.



Name:
Charles Baylis

Affiliation:
Wireless and Microwave Circuits and Systems Program, Department of Electrical and Computer Engineering, Baylor University

Address:
One Bear Place #97356, Waco, TX 76798-7356, USA

Brief Biographical History:

2007-2008 Visiting Assistant Professor, Department of Electrical Engineering, University of South Florida, Tampa, Florida

2008- Assistant Professor and Co-Director, Wireless and Microwave Circuits and Systems Program, Department of Electrical and Computer Engineering, Baylor University, Waco, Texas

Main Works:

- C. Baylis, S. Lardizabal, and L. Dunleavy, "A Fast Sequential Load-Pull Algorithm Implemented to Find Maximum Power," IEEE Wireless and Microwave Tech. Conf. (WAMICON 2006), Clearwater, Florida, 2006.
- C. Baylis, L. Wang, M. Moldovan, J. Martin, H. Miller, L. Cohen, and J. de Graaf, "Spectrum Issues in Power Amplifier Design," 2010 IEEE Waveform Diversity and Design Conf., Niagara Falls, Ontario, 2010.
- C. Baylis, M. Moldovan, L. Wang, and J. Martin, "LINC Power Amplifiers for Reducing Out-of-Band Spectral Re-growth: A Comparative Study," IEEE Wireless and Microwave Tech. Conf., Melbourne, 2010.
- C. Baylis, J. Perry, M. Moldovan, R. Marks, and L. Dunleavy, "Use of a Step-Response Approximation for Thermal Transient Modeling in Power MOSFETs," Automatic RF Techniques Group Conf., Broomfield, 2009.
- S. Meena, C. Baylis, L. Dunleavy, and M. Marbell, "Duty Cycle Dependent Pulsed IV Simulation and Thermal Time Constant Extraction for LDMOS Transistors," Automatic RF Techniques Group (ARFTG) Conf., Broomfield, Colorado, 2009.
- C. Baylis and L. Dunleavy (invited), "Electrothermal Nonlinear FET Modeling for Spectral Prediction," 2009 IEEE Electromagnetic Compatibility Symposium, Austin, Texas, 2009.
- C. Baylis, L. Dunleavy, and R. Connick (invited), "Modeling Considerations for GaN HEMT Devices," 2009 IEEE Wireless and Microwave Technology Conf. (WAMICON), Clearwater, Florida, 2009.
- S. Somasundaram Meena, C. Baylis, and L. Dunleavy, "Benchmarking Comparison of Thermal and Diode Sensors for Pulsed Power Measurement," 72nd Automatic RF Techniques Group Conf., Portland, 2008.
- C. Baylis and L. Dunleavy, "Voltage Transient Measurement and Extraction of Power RF MOSFET Thermal Time Constants," 70th Automatic RF Techniques Group Conf., Tempe, Arizona, 2007.
- C. Baylis, L. Dunleavy, and W. Clausen, "Design of Bias Tees for Pulsed-Bias S-Parameter Measurements Using Accurate Component Models," Microwave J., 2006.
- S. Akamatsu, C. Baylis, and L. Dunleavy, "Accurate Simulation Models Yield High Efficiency Power Amplifier Design," IEEE Microwave Magazine, 2005.
- C. Baylis, L. Dunleavy, and J. Daniel, "Direct Measurement of Thermal Circuit Parameters Using Pulsed IV and the Normalized Difference Unit," IEEE Microwave Theory and Tech. Society Int. Microwave Symposium, Fort Worth, Texas, 2004.

Membership in Academic Societies:

- Member, Institute of Electrical and Electronics Engineers (IEEE), Microwave Theory and Techniques Society
- Member, Automatic RF Techniques Group (ARFTG)

Name:
Lawrence Dunleavy

Affiliation:
University of South Florida

Address:
4202 E. Fowler Ave., ENB118, Tampa, FL, USA

Brief Biographical History:
1982 BSEE Michigan Technological University
1982-1983 Engineer, E-Systems
1983-1988 Fellow and Research Assistant, University of Michigan, Ann Arbor, Michigan
1984 MS from University of Michigan
1984-1990 Member of Technical Staff Hughes Aircraft Company
1988 Ph.D. from University of Michigan
1990- Assistant/Associate/Full Professor, Department of Electrical Engineering, University of South Florida, Tampa, Florida
2001-Presennt President & Co-founder Modelithics, Inc., Tampa Florida
1984-1990 Member of Technical Staff Hughes Aircraft Company

Main Works:
- J. Liu, L. P. Dunleavy, and H. Arslan, "Large Signal Behavioral Modeling of Nonlinear Amplifiers Based on Loadpull AM-AM and AM-PM Measurements," IEEE Trans. on Microwave Theory and Techniques, pp. 3191-3196, Aug. 2006.
- S. Padmanabhan, L. Dunleavy, J. Daniel, A. Rodríguez, and P. Kirby, "Broadband Space Conservative On-wafer Network Analyzer Calibrations with More Complex Load and Thru Models," IEEE Trans. on Microwave Theory and Tech., pp. 3583-3593, September 2006.
- M. Weatherspoon and L. P. Dunleavy, "Experimental Validation of Generalized Equations for FET Cold Noise Source Design," IEEE Trans. on Microwave Theory and Tech., Vol.54, Issue 2, Part 1, pp. 608-614, Feb. 2006.
- M. H. Weatherspoon and L. P. Dunleavy, "Vector Corrected On-Wafer Measurements of Noise Temperature," June 2005 IEEE Trans. Instrumentation and Measurements, Vol.54, Issue 3, pp. 1327-1332, June 2005.
- Rodriguez, L. Dunleavy, and A. Boudiaf, "Use of Induced Noise to Calibrate Injection-Locked Phase Noise Measurements," IEEE Microwave and Wireless Components Letters, Vol.11, No.3, March 2001.
- "Variable Microwave Cold/Warm Noise Source," US Serial No.09/319,520.
- "System and method for characterizing and simulating a frequency translating device," US Patent; Patent #7,299,166 Issued on the 20th, November 2007.

Membership in Academic Societies:
- Member, Institute of Electrical and Electronics Engineers (IEEE), Microwave Theory and Techniques Society
- Member, Automatic RF Techniques Group (ARFTG)
- Faculty Advisor Eta Kappa Nu Electrical Engineering Honor Society

Name:
Steven Lardizabal

Affiliation:
Raytheon RF Components

Address:
362 Lowell Street Andover, Massachusetts 01810, USA

Brief Biographical History:
1997- Senior Principal Electrical Engineer, Electrical Design Directorate, Raytheon RF Components

Main Works:
- C. Baylis, S. Lardizabal, and L. Dunleavy, "A Fast Sequential Load-Pull Algorithm Implemented to Find Maximum Power," IEEE Wireless and Microwave Technology Conf. (WAMICON 2006), Clearwater, Florida, December 2006.
- D. Qiao, R. Molfino, S. Lardizabal, B. Pillans, P. Asbeck, and G. Jerinic, "An Intelligently Controlled RF Power Amplifier With a Reconfigurable MEMS-Varactor Tuner," IEEE Trans.on Microwave Theory and Techniques, Vol.53, No.3, pp. 1089-1095, March 2005.

Membership in Academic Societies:
- Member, Institute of Electrical and Electronics Engineers (IEEE)

Name:
Robert J. Marks II

Affiliation:
Department of Electrical & Computer Engineering, Baylor University

Address:
One Bear Place, Waco, TX 76798-7356, USA

Brief Biographical History:
1977-2003 Department of Electrical Engineering, University of Washington, Seattle, WA
2003- Distinguished Professor of Electrical & Computer Engineering, Baylor University, Waco, Texas

Main Works:
- R. J. Marks II, "Handbook of Fourier Analysis and Its Applications," Oxford University Press, 2009.
- R. D. Reed and R. J. Marks II, "Neural Smithing: Supervised Learning in Feedforward Artificial Neural Networks," MIT Press, Cambridge, MA, 1999.
- R. J. Marks II, "Introduction to Shannon Sampling and Interpolation Theory," Springer-Verlag, 1991.
- R. J. Marks II, Editor, "Advanced Topics in Shannon Sampling and Interpolation Theory," Springer-Verlag, 1993.
- R. J. Marks II, Editor, "Fuzzy Logic Technology and Applications," IEEE Technical Activities Board, Piscataway, 1994.
- J. Zurada, R. J. Marks II, and C. J. Robinson, Editors, "Computational Intelligence: Imitating Life," IEEE Press, 1994.

Membership in Academic Societies:
- Fellow, Optical Society of America (OSA)
- Fellow, Institute of Electrical and Electronics Engineers (IEEE)

Name:
Alberto Rodriguez

Affiliation:
ITT Corporation, Palm Harbor, FL, USA

Brief Biographical History:
2008- Senior Engineer, ITT Corporation, Palm Harbor, FL, USA

Main Works:

• A. Rodriguez and L. Dunleavy, "A Method for Deembedding Mixed-Mode Power and Reflection Coefficient Measurements," in Wireless and Microwave Technology Conference, Clearwater Beach, FL, pp. 1-5, Dec. 2006.
• S. Padmanabhan, L. Dunleavy, J. E. Daniel, A. Rodríguez, and P. Kirby, "Broadband space conservative on-wafer network analyzer calibrations with more complex load and thru models," IEEE Trans. Microwave Theory Tech., Vol.54, pp. 3583-3593, Sept. 2006.
• P. L. Kirby, K. Herrick, R. Alm, N.A. Luque, A. Rodríguez, L. P. Dunleavy, and J. Papapolymerou, "W-band oscillator on metamorphic HEMT," in 2006 IEEE MTT-S Int. Microwave Symp. Dig., San Francisco, CA, pp. 735-738, June 2006.
• T. Büber et al., "Improved multimode calibration standards for 40 GHz measurements of active devices," in 65th Automatic RF Tech. Group Conf. Dig., Long Beach, CA, June 2005.
• T. Büber et al., "Multimode TRL and LRL calibrated measurements of differential devices," in 64th Automatic RF Tech. Group Conf. Dig., Orlando, FL, pp. 157-166, Dec. 2004.